(12) **United States Patent**
Zhu

(10) Patent No.: **US 6,359,916 B1**
(45) Date of Patent: **Mar. 19, 2002**

(54) **COHERENT POPULATION TRAPPING-BASED FREQUENCY STANDARD AND METHOD FOR GENERATING A FREQUENCY STANDARD INCORPORATING A QUANTUM ABSORBER THAT GENERATES THE CPT STATE WITH HIGH FREQUENCY**

(75) Inventor: **Miao Zhu, Palo Alto, CA (US)**

(73) Assignee: **Agilent Technologies, Inc., Palo Alto, CA (US)**

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 17 days.

(21) Appl. No.: **09/587,717**

(22) Filed: **Jun. 5, 2000**

(51) Int. Cl.^{7} H01S 3/13
(52) U.S. Cl. 372/32; 372/26; 372/28; 372/39
(58) Field of Search 372/32, 39, 26, 372/28

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,201,821 B1 * 1/2001 Zhu et al. 372/32
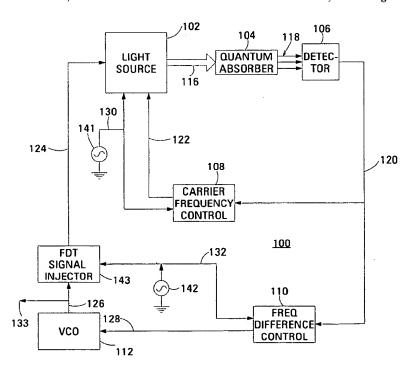
* cited by examiner

Primary Examiner—Leon Scott, Jr.

(74) *Attorney, Agent, or Firm*—Ian Hardcastle

(57) **ABSTRACT**

The frequency standard comprises a quantum absorber, source of incident electr-omagnetic radiation, detector, controller and signal output. The quantum absorber has a transition between a lower quantum state split by hyperfine interaction into two lower sub-state groups of at least one lower sub-state, and an upper quantum split by hyperfine interaction into upper sub-state groups of at least one upper sub-state. None of the upper sub-state groups is a cycling transition sub-state group having at least one allowed electric dipole transition to one lower sub-state group but none to the other. The upper quantum state differs in energy from a first lower sub-state in one of the lower sub-state groups and from a second lower sub-state in the other of the lower sub-state groups by energy differences that correspond to frequencies of ω_1 and ω_2, respectively. The source is arranged to irradiate the quantum absorber with the incident electro-magnetic radiation that includes two main frequency components having frequencies equal to ω_1 and ω_2. The detector generates a detection signal in response to electromagnetic radiation from the quantum absorber. The controller is responsive to the detection signal and controls the source to generate the main frequency components with a frequency difference that obtains an extremum in the detection signal. The extremum indicates that the frequency difference corresponds to an energy difference between the first and second lower sub-states. The signal output provides a frequency standard signal related in frequency to the frequency difference.

20 Claims, 5 Drawing Sheets